DESCRIPTION

SEMICONDUCTOR LASER CAPABLE OF COUPLING WITH SINGLE MODE OPTICAL FIBER AT HIGH COUPLING EFFICIENCY

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Technical Field

The present invention relates to a semiconductor laser, and more particularly to a semiconductor laser capable of coupling with a single mode optical fiber at

10   high coupling efficiency.

Background Art

An optical signal for use in an optical communica-tion system is transmitted in an optical fiber laid down over a long distance. Hence, as the characteris-

15   tic of a semiconductor laser used as a light source of the light, high output and high stability are required.

When a single mode optical fiber is used in transmission of an optical signal, the semiconductor laser as a light source and the single mode optical

20   fiber are coupled optically.

However, when a device end face of the semiconduc-tor laser and a light incident plane of the optical fiber are directly coupled by means of butt joint, the light wave spot size of the semiconductor laser is 2 to

25   3 μm while the spot size of the single mode optical fiber is about 10 μm, so that coupling loss occurs due to difference in light wave spot size between mutual optical waveguides.

Generally, therefore, it is attempted to reduce the coupling loss by converting the laser light from the semiconductor laser into the spot size of the optical fiber by using a lens.

5   In the configuration using a lens in optical coupling, however, it requires complicated optical axis adjustment between the semiconductor laser and the optical fiber, and the number of optical components is increased.

10   To solve these problems, there has been proposed a semiconductor optical device capable of coupling optically with a single mode optical fiber by using a lens as disclosed in the following patent document 1.

FIG. 17 is a perspective view showing a schematic

15   configuration of the semiconductor optical device disclosed in patent document 1.

As shown in FIG. 17, a semiconductor optical device 51 disclosed in patent document 1 comprises components 52 necessary for forming devices such as

20   a cladding, a cap and an electrode, in which a multiquantum well (MQW) active layer 53 is coupled to a taper optical waveguide 55 by way of a butt joint part 54.

The MQW active layer 53 is a distortion

25   super-grating active layer, which composes an active region 56. The light waveguide 55 is a light waveguide whose layer thickness and band gap wavelength are

continuously changed, and composes a spot size
conversion region 57.

In the case of coupling optically with a single
mode optical fiber by using the semiconductor optical
device 51, laser light emitted from the active region
56 of the MQW active layer 53 is propagated to the spot
size conversion region 57 of the taper light waveguide
55 through the butt joint part 54, is converted in the
spot size in the spot size conversion region 57, and is
emitted from a light exit facet 55a.

The laser light converted in spot size is input
into the light incident plane of the single mode
optical fiber from the light exit facet 55a, and
thereby the semiconductor optical device 51 and the
single mode optical fiber are optically coupled.
Patent document 1: Jpn. Pat. Appln. KOKAI Publication
No. 9-61652

However, in the conventional semiconductor optical
device 51 having the taper light waveguide 55 disclosed
in patent document 1, the taper light waveguide 55 must
be formed integrally with the semiconductor optical
device 51 so that the spot size of the laser light
emitted from the light exit facet 55a is matched with
the spot size of the single mode optical fiber.
Therefore, it is hard to design, it takes much time and
labor in manufacture, and repeatability of manufacture
is poor.

Incidentally, by expanding the width of the active layer of the semiconductor laser, the spot diameter of the laser light emitted from the semiconductor laser can be adjusted to the core diameter of the single mode optical fiber.

However, by merely expanding the width of the active layer of the semiconductor laser alone, a lateral harmonic mode is generated in the laser light emitted from the semiconductor laser, so that a discontinuous point is formed as regards the current-light output characteristic, and coupling loss is increased at the time of optically coupling with the single mode optical fiber, which poses a new problem.

The present inventors or the like previously disclosed, in US patent application No. 10/692,125 and European patent application No. 03 025 058.3, a semiconductor light emitting device applicable to a semiconductor laser, which is capable of obtaining a light output of higher power in a simple configuration, and expanding the maximum width of an active layer that can suppress a lateral harmonic mode because an n-type cladding layer is made of InGaAsP having larger refractive index than a p-type cladding layer made of InP.

These prior applications, however, does not suppose that a semiconductor laser and a single mode optical fiber are optically coupled without using

a lens in order to transmit an optical signal from the
semiconductor laser as a light source as considered in
the present invention, and thus, the expandable width
of the active layer is 3.5 μm or more, and 4.0 μm at

5   maximum.

Therefore, if the semiconductor light emitting
device disclosed in these prior applications is
applied in a semiconductor laser as a light source
used in an optical communication system, the expandable

10   width of an active layer is 3.5 μm to 4.0 μm at most.
Consequently, it is not realistic from the viewpoint
of coupling loss to couple the semiconductor laser and
a single mode optical fiber optically without using
a lens.

15   Disclosure of Invention

The invention has been devised in light of the
above problems, and it is hence a primary object of the
invention to provide a semiconductor laser capable of
coupling laser light of high output with a single mode

20   optical fiber at high coupling efficiency at low cost
while maintaining a fundamental lateral mode, without
requiring any lens as required in the prior art or
other spot size converters when coupling optically with
the single mode optical fiber.

25   In order to achieve the above object, according
to a first aspect of the present invention, there is
provided a semiconductor laser comprising:

a substrate (2) made of InP;

an active layer (5) including a multiquantum well structure formed above the substrate (2) in a width of 7 to 14 µm; and

an n-type cladding layer (3) made of InGaAsP and a p-type cladding layer (9) made of InP which are formed above the substrate (2) with the active layer interposed therebetween, wherein

light which oscillates only in a fundamental lateral mode to be emitted from an exit facet is optically coupled with an external single mode optical fiber (31).

In order to achieve the above object, according to a second aspect of the present invention, there is provided a semiconductor laser according to the first aspect, wherein the light emitted from the exit facet is optically coupled with the external single mode optical fiber without resort to lens.

In order to achieve the above object, according to a third aspect of the present invention, there is provided a semiconductor laser according to the first aspect, wherein the light emitted from the exit facet is optically coupled with the external single mode optical fiber by butt joint.

In order to achieve the above object, according to a fourth aspect of the present invention, there is provided a semiconductor laser according to the first

aspect, further comprising:

a first separate confinement heterostructure (SCH) layer (4) made of InGaAsP, which is formed between the active layer and the n-type cladding layer; and

a second SCH layer (6) made of InGaAsP, which is formed between the active layer and the p-type cladding layer.

In order to achieve the above object, according to a fifth aspect of the present invention, there is provided a semiconductor laser according to the fourth aspect, wherein

the first SCH layer includes a multilayer structure formed of a plurality of layers (4a, 4b, 4c, ... 4N), and

the second SCH layer includes a multilayer structure formed of a plurality of layers (6a, 6b, 6c, ... 6N).

In order to achieve the above object, according to a sixth aspect of the present invention, there is provided a semiconductor laser according to the fifth aspect, wherein

assuming that a refractive index of a plurality of partition layers in the active layer is ns;

that a refractive index and thickness of the plurality of layers in the first SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from a side closer to the active layer;

and

that a refractive index and thickness of the plurality of layers in the second SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from the side closer to the active layer, a relationship of the thicknesses of the layers is mutually uniform, being set in a relation of:

$$t1 = t2 = t3 = , ..., = tN,$$

a great and small relationship of the refractive indexes of the layers is set so as to be smaller as going further from the active layer as shown below, including a relationship in which the refractive index ns of the active layer is highest, and a refractive index na of the n-type cladding layer is higher than a refractive index nb of the p-type cladding layer:

$$ns > n1 > n2 > n3 >, ..., nN > na > nb, and$$

further

a refractive index difference between mutually adjacent layers among the plurality of layers which compose the first SCH layer and second SCH layer is set to be smaller as going from the active layer to the n-type cladding layer and p-type cladding layer in a relationship of:

$$ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na.$$

In order to achieve the above object, according to a seventh aspect of the present invention, there is provided a semiconductor laser according to the fifth

aspect, wherein

assuming that a refractive index of a plurality of partition layers in the active layer is ns;

that a refractive index and thickness of the plurality of layers in the first SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from a side closer to the active layer; and

that a refractive index and thickness of the plurality of layers in the second SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from the side closer to the active layer, a great and small relationship of the refractive indexes of the layers is set so as to be smaller as going further from the active layer as shown below, including a relationship in which the refractive index ns of the active layer is highest, and a refractive index na of the n-type cladding layer is higher than a refractive index nb of the p-type cladding layer:

ns > n1 > n2 > n3 >, ..., nN > na > nb,

a refractive index difference between mutually adjacent layers among the plurality of layers which compose the first SCH layer and second SCH layer is set to be in a relationship of:

ns-n1 = n1-n2 = n2-n3 =, ..., = nN-nb (provided that nN-nb > nN-na), and

a relationship of the thicknesses of the layers is

set in the following relation so as to be larger as
being more remote from the active layer:

$t1 < t2 < t3, ..., < tN$.

In order to achieve the above object, according to
an eighth aspect of the present invention, there is
provided a semiconductor laser according to the fifth
aspect, wherein

assuming that a refractive index of a plurality of
partition layers in the active layer is ns;

that a refractive index and thickness of the
plurality of layers in the first SCH layer are n1, n2,
n3, ..., nN and t1, t2, t3, ..., tN, respectively,
sequentially from a side closer to the active layer;
and

that a refractive index and thickness of the
plurality of layers in the second SCH layer are n1, n2,
n3, ..., nN and t1, t2, t3, ..., tN, respectively,
sequentially from the side closer to the active layer,

a great and small relationship of the refractive
indexes of the layers is set so as to be smaller as
going further from the active layer as shown below,
including a relationship in which the refractive index
ns of the active layer is highest, and a refractive
index na of the n-type cladding layer is higher than
a refractive index nb of the p-type cladding layer:

$ns > n1 > n2 > n3 >, ..., nN > na > nb$,

a refractive index difference between mutually

adjacent layers among the plurality of layers which compose the first SCH layer and second SCH layer is set to be smaller as going further from the active layer in a relationship of:

$$ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na,$$ and

a relationship of the thicknesses of the layers is set in the following relation so as to be larger as being more remote from the active layer:

$$t1 < t2 < t3 <, ..., < tN.$$

In order to achieve the above object, according to a ninth aspect of the present invention, there is provided a semiconductor laser according to the fifth aspect, wherein

assuming that a refractive index of a layer having the lowest refractive index among the layers forming the active layer is ns;

that a refractive index and thickness of the plurality of layers in the first SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from a side closer to the active layer; and

that a refractive index and thickness of the plurality of layers in the second SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from the side closer to the active layer,

a relationship of the thicknesses of the layers is set to be equal to each other in a relationship of:

$t1 = t2 = t3 =, ..., = tN,$

a great and small relationship of the refractive indexes of the layers is set so as to be smaller as going further from the active layer as shown below, including a relationship in which the refractive index ns of the active layer is highest, and a refractive index na of the n-type cladding layer is higher than a refractive index nb of the p-type cladding layer:

$ns > n1 > n2 > n3 >, ..., nN > nb,$ and also

$na > nN,$ and

a refractive index difference between mutually adjacent layers among the plurality of layers which compose the first SCH layer and second SCH layer is set to be smaller as going from the active layer to the n-type cladding layer and the p-type cladding layer in a relationship of:

$ns-n1 > n1-n2 > n2-n3 >, ..., > n(N-1)-nN.$

In order to achieve the above object, according to a tenth aspect of the present invention, there is provided a semiconductor laser according to the fifth aspect, wherein

assuming that a refractive index of a layer having the lowest refractive index among the layers forming the active layer is ns;

that a refractive index and thickness of the plurality of layers in the first SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively,

sequentially from a side closer to the active layer; and

that a refractive index and thickness of the plurality of layers in the second SCH layer are n1, n2,

5   n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from the side closer to the active layer,

a great and small relationship of the refractive indexes of the layers is set so as to be smaller as going further from the active layer as shown below,

10   including a relationship in which the refractive index ns of the active layer is highest, and a refractive index na of the n-type cladding layer is higher than a refractive index nb of the p-type cladding layer:

ns > n1 > n2 > n3 >, ..., nN > nb, and also

15   na > nN,

a refractive index difference between mutually adjacent layers among the plurality of layers which compose the first SCH layer and second SCH layer is set to be in a relation of:

20   ns-n1 = n1-n2 = n2-n3 =, ..., = nN-nb, and

relationship of the thicknesses of the layers is set to be larger as being more remote from the active layer in a relation of:

t1 < t2 < t3 <, ..., < tN.

25   In order to achieve the above object, according to an eleventh aspect of the present invention, there is provided a semiconductor laser according to the fifth

aspect, wherein

assuming that a refractive index of a layer having the lowest refractive index among the layers forming the active layer is ns;

5 that a refractive index and thickness of the plurality of layers in the first SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from a side closer to the active layer; and

10 that a refractive index and thickness of the plurality of layers in the second SCH layer are n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, sequentially from the side closer to the active layer,

a great and small relationship of the refractive 15 indexes of the layers is set so as to be smaller as going further from the active layer as shown below, including a relationship in which the refractive index ns of the active layer is highest, and a refractive index na of the n-type cladding layer is higher than 20 a refractive index nb of the p-type cladding layer:

ns > n1 > n2 > n3 >, ..., nN > nb, and also

na > nN,

a refractive index difference between mutually adjacent layers among the plurality of layers which 25 compose the first SCH layer and second SCH layer is set to be smaller as going further from the active layer in a relationship of:

ns-n1 > n1-n2 > n2-n3 >, ..., > n(N-1)-nN, and

a relationship of the thicknesses of the layers is set to be larger as being more remote from the active layer in a relationship of:

5   t1 < t2 < t3 <, ..., < tN.

In order to achieve the above object, according to a twelfth aspect of the present invention, there is provided a semiconductor laser according to the fourth aspect, wherein the semiconductor laser is formed in

10   a buried heterostructure.

In order to achieve the above object, according to a thirteenth aspect of the present invention, there is provided a semiconductor laser according to the twelfth aspect, wherein

15   part of the n-type cladding layer, the first SCH layer, the active layer, the second SCH layer, and the p-type cladding layer is formed in a mesa shape, and

the semiconductor laser further comprises:

a first buried layer (7) made of p-type InP, which

20   is formed with one side thereof in contact with the semiconductor substrate or the n-type cladding layer at both sides of each layer formed in the mesa shape; and

a second buried layer (8) made of n-type InP, which is formed with one side thereof in contact with

25   the p-type cladding layer and the other side thereof in contact with the other side of the first buried layer (7) at both sides of each layer formed in the mesa

shape.

In order to achieve the above object, according to a fourteenth aspect of the present invention, there is provided a semiconductor laser according to the first

5   aspect, wherein the semiconductor laser is formed in a ridge structure.

In order to achieve the above object, according to a fifteenth aspect of the present invention, there is provided a semiconductor laser according to the

10   fourteenth aspect, wherein

when the semiconductor substrate is an n-type, the p-type cladding layer is formed as a ridge structure portion with substantially the center of the outside being raised to the upside, and

15   the semiconductor laser further comprises:

a contact layer (10) formed on a upside of the ridge structure portion in the p-type cladding layer;

an insulating layer (23) having an opening portion above a center of the contact layer and which is formed

20   to cover the p-type cladding layer including the ridge structure portion; and

an electrode (11) formed on a top of the insulating layer with a part thereof connected to the contact layer.

25   In order to achieve the above object, according to a sixteenth aspect of the present invention, there is provided a semiconductor laser according to the first

aspect, wherein a bandgap wavelength of InGaAsP which composes the n-type cladding layer is a bandgap wavelength of InP or more and 0.98 μm or less.

In order to achieve the above object, according to a seventeenth aspect of the present invention, there is provided a semiconductor laser according to the sixteenth aspect, wherein a bandgap wavelength of InGaAsP which composes the n-type cladding layer is 0.96 μm or more and 0.98 μm or less.

In order to achieve the above object, according to an eighteenth aspect of the present invention, there is provided a semiconductor laser according to the first aspect, wherein, when the semiconductor substrate is an n-type, the n-type cladding layer is formed beneath the active layer, and the p-type cladding layer is formed above the active layer.

In order to achieve the above object, according to a nineteenth aspect of the present invention, there is provided a semiconductor laser according to the first aspect, wherein, when the semiconductor substrate is a p-type, the n-type cladding layer is formed above the active layer, and the p-type cladding layer is formed beneath the active layer.

According to the semiconductor laser of the invention, the n-type cladding layer (3) is composed of four elements In, Ga, As and P, the bandgap wavelength of the n-type cladding layer (3) is 0.96 to 0.98 μm,

and the width of the active layer (5) is 7 to 14 μm.
Accordingly, wile maintaining the oscillation
fundamental lateral mode, the laser light of high
output can be coupled with an external single mode

5   optical fiber at high coupling efficiency.

Further, according to the semiconductor laser of
the invention, the lens, taper light waveguide, and
other spot size converters as used in the prior art
are not required, so that the manufacturing process is

10   simplified, the device length is shortened, and the
device cost can be lowered.

Brief Description of Drawings

FIG. 1 is a perspective view showing a schematic
configuration of a semiconductor laser according to

15   a first embodiment of the invention.

FIG. 2 is a sectional view of essential parts of
the semiconductor laser according to the first
embodiment of the invention.

FIG. 3 is a diagram showing the refractive index

20   characteristic of each layer of the semiconductor laser
according to the first embodiment of the invention.

FIG. 4 is a diagram showing the relation between
the horizontal spot diameter of exit light and optical
coupling efficiency with a single mode optical fiber,

25   in terms of a flatness rate of an optical spot of the
semiconductor laser according to the first embodiment
of the invention.

FIG. 5 is a diagram showing the relation between the horizontal spot diameter and a spreading angle of a far viewing field image of laser exit light of the semiconductor laser according to the first embodiment of the invention.

FIG. 6 is a diagram showing the relation between the width of an active layer and the spreading angle of the far viewing field image of the laser exit light of the semiconductor laser according to the first embodiment of the invention.

FIG. 7 shows an example of relation diagram of the maximum active layer width (= cut-off width) capable of suppressing a lateral harmonic mode, in relation to the bandgap wavelength of InGaAsP for use in an n-type cladding layer in the same active layer structure of the semiconductor laser according to the first embodiment of the invention.

FIG. 8 is a diagram showing distribution characteristic of light of the semiconductor laser according to the first embodiment of the invention.

FIG. 9 is a diagram showing refractive index characteristic of each layer of a semiconductor laser according to another embodiment of the invention.

FIG. 10 is a diagram showing refractive index characteristic of each layer of a semiconductor laser according to another embodiment of the invention.

FIG. 11 is a diagram showing supply current and

output characteristic of the semiconductor laser shown in FIG. 10 according to the another embodiment of the invention.

FIG. 12 is a view for explaining a semiconductor laser of a ridge structure according to another embodiment of the invention.

FIG. 13 is a view showing an example of configuration on a p-type substrate as a semiconductor laser according to another embodiment of the invention.

FIG. 14 is a diagram showing refractive index characteristic of each layer of a semiconductor laser according to another embodiment of the invention.

FIG. 15 is a diagram showing an example and another example of optical coupling between a semiconductor laser and an external single mode optical fiber according to the invention.

FIG. 16 is a diagram showing refractive index characteristic of each layer of a semiconductor laser according to another embodiment of the invention.

FIG. 17 is a perspective view of a conventional semiconductor optical device disclosed in patent document 1.

Best Mode for Carrying Out the Invention

A semiconductor laser according to embodiments of the invention will be described below with reference to the accompanying drawings.

FIG. 1 is a perspective view of an entire

configuration of a semiconductor laser according to
a first embodiment of the invention, and FIG. 2 is a
partially enlarged sectional view of the semiconductor
laser according to the first embodiment of the

5   invention.

As shown in FIG. 1, a semiconductor laser 1
according to the first embodiment of the invention
comprises an n-type cladding layer 3 made of n-type
InGaAsP, a first separate confinement heterostructure

10   (SCH) layer 4 made of InGaAsP, an active layer 5 made
of InGaAsP, and a second SCH layer 6 made of InGaAsP
which are sequentially laminated on a semiconductor
substrate 2 made of n-type InP.

In FIG. 1, the n-type cladding layer 3, the first

15   SCH layer 4, the active layer 5, and the second SCH
layer 6 are formed in a mesa shape, and at both sides
of the mesa shape, a lower buried layer 7 made of
p-type InP and an upper buried layer 8 made of n-type
InP are formed.

20   Further, a p-type cladding layer 9 made of p-type
InP is formed on the upper side of the second SCH layer
6 and on the top face of the upper buried layer 8. On
the top face of the p-type cladding layer 9, a p-type
contact layer 10 is formed. Further, on the top face

25   of the p-type cladding layer 10, a p electrode 11 is
provided. In addition, an n electrode 12 is provided
on the lower side of the semiconductor substrate 2.

In the semiconductor laser according to the first embodiment of the invention, as shown in FIG. 2, the active layer 5 employs a four-layer multiquantum well (MQW) structure in which four layers of well layer 5a, and five layers of partition layer 5b positioned at both sides of these well layers 5a are laminated.

The first SCH layer 4 positioned at the lower side of the active layer 5 having such a four-layer MQW structure is composed of multiple layers 4a, 4b, 4c, ..., 4N, and similarly the second SCH layer 6 positioned at the lower side of the active layer 5 is composed of multiple layers 6a, 6b, 6c, ..., 6N.

As shown in FIG. 2, a refractive index of the partition layer 5b in the active layer 5 is supposed to be ns, a refractive index of the n-type cladding layer 3 to be na, and a refractive index of the p-type cladding layer 9 to be nb.

A refractive index and thickness of the layers 4a, 4b, 4c, ..., 4N for composing the first SCH layer 4 are supposed to be n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively, and similarly a refractive index and thickness of the layers 6a, 6b, 6c, ..., 6N for composing the second SCH layer 6 are supposed to be n1, n2, n3, ..., nN and t1, t2, t3, ..., tN, respectively.

The great and small relationship of the refractive indexes is set so as to be smaller as going further

from the active layer 5 as shown in the inequality
below, and the refractive index na of the n-type
cladding layer 3 made of InGaAsP is set higher than the
refractive index nb of the p-type cladding layer 9 made

5   of InP as shown in the inequality below.

ns > n1 > n2 > n3 >, ..., nN > na > nb

Further, in the semiconductor laser 1, as shown in
FIG. 3, a refractive index difference between mutually
adjacent layers for composing the first SCH layer 4 and

10   second SCH layer 6 is set to be smaller as going from
the active layer 5 to the cladding layer 3, 9.

That is, the refractive index difference between
mutually adjacent layers for composing the first SCH
layer 4 and second SCH layer 6 is set as shown in the

15   inequality below.

ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na

The thicknesses t1, t2, t3, ..., tN of the layers
for composing the first SCH layer 4 and second SCH
layer 6 are set equally.

20   That is, the thicknesses of the layers are set as
follows.

t1 = t2 = t3 = , ..., = tN

In the semiconductor laser 1 having such a
configuration, when a direct-current voltage is applied

25   between the p electrode 11 and the n electrode 12,
light P is generated in the active layer 5, and the
light P is emitted outside from the end faces 1a, 1b of

the semiconductor laser 1 shown in FIG. 1.

Herein, in the semiconductor laser 1, the width of active layer 5 capable of obtaining sufficient coupling efficiency with the single mode optical fiber while suppressing generation of the lateral harmonic mode will be explained.

That is, in the semiconductor laser 1, as mentioned above, when the light P generated in the active layer 5 is emitted outside from the end faces 1a, 1b of the semiconductor laser 1, the exit light is emitted outside in a predetermined spot diameter.

The spot diameter is a diameter of a portion with maximum light intensity $1/e^2$ (e the being the base of a natural logarithm) in light intensity distribution at an end of the active layer 5, of the light emitted from the end.

FIG. 4 is a diagram showing the relation between a horizontal spot diameter of the exit light and optical coupling efficiency with the single mode optical fiber, in terms of a flatness rate of a light spot in the semiconductor laser 1 of the invention.

The flatness rate of the light spot is a ratio of the spot diameter in the horizontal direction: vertical direction, and ratios 1:1.35, 1:1.2, 1:1, 1:0.8, and 1:0.65 are shown.

The semiconductor laser 1 oscillates in the fundamental lateral mode, and the light emitted from

the end faces la, lb of the semiconductor laser 1 is optically coupled, without lens, for example, with the single mode optical fiber disposed closely to either one of the end faces la, lb of the semiconductor laser 1 as described below.

As known from FIG. 4, in the semiconductor laser 1 of the invention, the required horizontal spot diameter is 7 to 14 μm in order to obtain high optical coupling efficiency of about 75% or more at any flatness rate of the light spot.

FIG. 5 is a diagram showing the relation between the horizontal spot diameter and a spreading angle of a far viewing field image of a laser exit light in semiconductor laser 1 of the invention.

FIG. 6 is a diagram showing the relation between the width of the active layer 5 and the spreading angle of the far viewing field image of the laser exit light in semiconductor laser 1 of the invention.

As is clear from comparison between FIG. 5 and FIG. 6, in the semiconductor laser 1 of the invention, the width of the active layer 5 and the horizontal spot diameter when the same spreading angle is obtained are substantially equal to each other.

Therefore, it may be assumed that the width of the active layer 5 = spot diameter in the semiconductor laser 1 of the embodiment.

Accordingly, in the semiconductor laser 1 of the

embodiment, it is sufficient when the width of the active layer 5 is 7 to 14 μm in order to obtain a high optical coupling efficiency of about 75% or more in optical coupling with the single mode optical fiber.

5   In this kind of semiconductor laser 1, merely by expanding the active lager width, the lateral harmonic mode is generated in the oscillation mode of the laser, so that not only the laser characteristic is impaired, but also the optical coupling efficiency with the fiber

10   is lowered.

In the semiconductor laser 1 of the embodiment, as mentioned above, the n-side cladding layer is composed of InGaAsP, whereby the same effects are obtained as when decreasing the equivalent refractive index of

15   an optical waveguide for guiding the light inside the semiconductor laser 1. Consequently, a semiconductor laser of wide active layer width while suppressing generation of the lateral harmonic mode can be realized.

20   As stated above, the present inventors or the like previously disclosed, in US patent application No. 10/692,125 and European patent application No. 03 025 058.3, a semiconductor light emitting device applicable to a semiconductor laser, which is capable

25   of obtaining a light output of higher power in a simple configuration, and expanding the maximum width of an active layer that can suppress a lateral harmonic mode

because an n-type cladding layer is made of InGaAsP
having larger refractive index than a p-type cladding
layer made of InP.

These prior applications, however, do not suppose
that a semiconductor laser and a single mode optical
fiber are optically coupled without using a lens in
order to transmit an optical signal from the semicon-
ductor laser as a light source as considered in the
present invention, and thus, the expandable width of
the active layer is 3.5 μm or more, and 4.0 μm at
maximum.

Therefore, if the semiconductor light emitting
device disclosed in these prior applications is applied
in a semiconductor laser as a light source used in
an optical communication system, the expandable width
of an active layer is 3.5 μm to 4.0 μm at most.
Consequently, it is not realistic from the viewpoint
of coupling loss to couple the semiconductor laser and
a single mode optical fiber optically without using
a lens.

In these prior applications, in the semiconductor
laser 1 of the invention, nothing is analyzed or
discussed about the required width of the active layer
5 of 7 to 14 μm in order to obtain high optical
coupling efficiency of about 75% or more in optical
coupling with the single mode optical fiber.

FIG. 7 shows an example of the relation of the

maximum active layer width (= cut-off width) capable

of suppressing the lateral harmonic mode, in relation

to bandgap wavelength of InGaAsP used in the n-type

cladding layer in the same active layer structure of

5   the semiconductor laser 1 of the invention.

According to this relation, as in the case of

a semiconductor laser using an ordinary InP cladding

layer with bandgap wavelength of 0.925 μm in the n-side

cladding layer, the cut-off width is about 3.5 μm in

10   the semiconductor laser using InGaAsP with a bandgap

wavelength of 0.925 μm in the n-side cladding layer.

By contrast, when the bandgap wavelength of

InGaAsP used in the n-side cladding layer is 0.96 μm,

the cut-off width is about 7 μm, and further when the

15   bandgap wavelength is 0.98 μm, the cut-off width can be

expanded up to about 14 μm.

Referring to FIG. 3, the refractive index of each

layer of the semiconductor laser 1 in this embodiment

will be explained.

20   As shown in the refractive index characteristic in

FIG. 3, in the semiconductor laser 1 of the embodiment,

the refractive index difference of mutually adjacent

layers among the layers 4a, 4b, 4c, 6a, 6b, 6c for

composing the first and second SCH layers 4, 6 is set

25   to be smaller as going from the active layer 5 to the

cladding layers 3, 9.

As a result, in the semiconductor laser 1 of the

embodiment, the refractive index drops suddenly in a region with high refractive index in the neighboring region of the active layer 5 in the first and second SCH layers 4, 6, while the refractive index declines slowly in a region with low refractive index in the neighboring region of both the cladding layers 3, 9.

Hence, the degree of concentration of light is lessened in the optical waveguide for guiding the light inside the semiconductor laser 1 of the embodiment, that is, the light confinement coefficient can be lowered, and the internal loss declines.

In the semiconductor laser 1 of the embodiment, the refractive index na of the n-type cladding layer 3 made of InGaAsP is higher than the refractive index nb of the p-type cladding layer 9 made of InP. Therefore, as shown in FIG. 8, the light distribution is biased to the n-type cladding layer 3 side as indicated by characteristic curve A, as compared with symmetrical characteristic curve A' of the same refractive index in both the cladding layers 3, 9.

Accordingly, in the semiconductor laser 1 of the embodiment, it is possible to suppress increase of optical loss due to light absorption between valence bands in the p-type cladding layer 9 by lowering the light confinement coefficient in the active layer 5 and first and second SCH layers 4, 6, so that laser light of high output can be obtained.

Also in the semiconductor laser 1 of the embodiment, the refractive index difference of active layer 5 and n-type cladding layer 3 is smaller than in the prior art, and thus, the maximum active layer width

5 capable of suppressing the lateral harmonic mode can be also expanded, which is further advantageous for higher output of the laser.

Specifically, in the semiconductor laser 1 of the embodiment, the bandgap wavelength of the n-type

10 cladding layer is set in a range of 0.96 to 0.98 μm, whereby the maximum active layer width capable of suppressing the lateral harmonic mode can be expanded to about 7 to 14 μm.

Consequently, in the semiconductor laser 1 of the

15 embodiment, not only the drop of the optical output due to increase of the device resistance value can be prevented, but also the light spot size can be expanded, and therefore, it is possible to couple to the single mode optical fiber, for example, without

20 a lens as described later.

In the semiconductor laser 1 of the embodiment, moreover, it is not required to increase the thickness of the p-type cladding layer 9, and there is no risk of drop of the optical output due to increase of the

25 device resistance value.

Herein, as a method of decreasing the light confinement coefficient in the active layer 5 and first

and second SCH layers 4, 6, the refractive index difference between mutually adjacent layers for composing the first and second SCH layers 4, 6 is set to be smaller as going away from the active layer 5, and each layer is formed in a uniform thickness.

Not limited to this method, in a semiconductor laser 1 of another embodiment, as shown in FIG. 9, by equalizing the refractive index difference between mutually adjacent layers for composing the first and second SCH layers 4, 6, and setting the thickness of the layers to be larger as being more remote from the active layer 5, the relationship may be set as shown in the two formulas below:

ns-n1 = n1-n2 = n2-n3 =, ..., = nN-nb (provided that nN-nb > Nn-na), and

t1 < t2 < t3, ..., < tN.

In a semiconductor laser 1 of a further embodiment, as shown in FIG. 10, the refractive index difference between mutually adjacent layers for composing the first and second SCH layers 4, 6 may be set to be smaller as going away from the active layer 5, and the thickness of the layers to be larger as being more remote from the active layer 5, as shown in the two formulas of inequality below;

ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na, and

t1 < t2 < t3, ..., < tN.

Even in the case where the refractive index

characteristic of the layers of the semiconductor laser
1 is set as shown above in FIGS. 9 and 10, the
refractive index drops suddenly in a region with high
refractive index in the neighboring region of the
5   active layer 5 in the first and second SCH layers 4, 6,
while the refractive index declines slowly in a region
with low refractive index in the neighboring region of
both the cladding layers 3, 9.

Therefore, the degree of concentration of light
10   is lessened in the optical waveguide for guiding the
light inside the semiconductor laser 1 in these other
embodiments, that is, the light confinement coefficient
can be set lower, so that the internal loss declines.

Even in the case of the semiconductor laser 1 of
15   any embodiment, the refractive index na of the n-type
cladding layer 3 made of InGaAsP is higher than the
refractive index nb of the p-type cladding layer 9 made
of InP. Therefore, as shown in FIG. 8, the light
distribution is biased to the n-type cladding layer 3
20   side.

Even in the case of the semiconductor laser 1 of
any embodiment, by lowering the light confinement
coefficient in the active layer 5 and first and second
SCH layers 4, 6, it is effective to suppress increase
25   of optical loss due to light absorption between valence
bands in the p-type cladding layer 9, so that laser
light of high output can be obtained.

Concerning the refractive index and thickness of the parts of a semiconductor laser 1 in another embodiment shown in FIG. 10, specific numerical value examples and their characteristics are shown below.

In the semiconductor laser 1 of the embodiment, the resonator length L is set at L = 3 mm in the configuration shown in FIG. 1.

One of the end faces 1a, 1b in the semiconductor laser 1 is a high reflection (HR) film, and the other is a low reflection (LF) film.

The width of the active layer 5 in the semiconductor laser 1 is set at 9.0 μm.

In this semiconductor laser 1, the refractive indices ns, n1, n2, n3, na, nb of the layers 4a, 4b, 4c, 6a, 6b, 6c are set as follows as bandgap wavelengths.

ns = 1.2 μm

$n1$ = 1.15 μm

$n2$ = 1.08 μm

$n3$ = 0.99 μm

na = 0.97 μm

nb = 0.925 μm

Since the p-type cladding layer 9 is composed of InP of which composition is determined, its bandgap wavelength nb is uniquely 0.925 μm.

The thicknesses t1, t2, t3 of these layers 4a, 4b, 4c, 6a, 6b, 6c of the semiconductor laser 1 are set as

follows.

t1 = 3.0 nm

t2 = 8.0 nm

t3 = 25 nm

The thickness of the n-type cladding layer 3 is about 7.5 μm, but it is difficult with general manufacturing technology to form in this thickness by matching with the grating intervals of four-element composition of InGaAsP.

In particular, when the bandgap wavelength na of the n-type cladding layer 3 is 0.97 μm, the rate of Ga and As is very small as compared with In and P, and thus, it is further difficult to form in this thickness.

In the invention, therefore, by feeding diluting materials and controlling the flow rate of each gas and growth speed, it is possible to realize the n-type cladding layer 3 with a bandgap wavelength na of 0.97 μm formed in a sufficient thickness of about 7.5 μm.

An example of its manufacturing process will be explained below.

First, on a semiconductor substrate 2 made of n-type InP with impurity concentration of 1 to 2 × 10^{18}/cm^3, an n-type cladding layer 3 made of InGaAsP of bandgap wavelength of 0.97 μm with impurity concentration of 1 to 2 × 10^{18}/cm^3 is formed in a film

thickness of 0.75 μm by a metal organic vapor phase epitaxial growth (MOVPE) method.

Next, nondoped InGaAsP layers of bandgap wavelengths of 0.99 μm, 1.08 μm and 1.15 μm are laminated in thicknesses of 25 nm, 8 nm and 3 nm, respectively, and an SCH layer 4 is formed.

On the first SCH layer 4, a well layer 5a made of InGaAsP and a partition layer 5b made of InGaAsP are grown alternately, and an active layer 5 in a multi-quantum well structure of four well layers is formed.

On the active layer 5, nondoped InGaAsP layers of bandgap wavelengths of 1.15 μm, 1.08 μm and 0.99 μm are laminated in thicknesses of 3 nm, 8 nm and 25 nm, respectively, and a second SCH layer 6 is formed.

On the second SCH layer 6, a lower layer of a p-type cladding layer 9 made of InP is formed in a thickness of 0.5 μm at impurity concentration of 5 to $7 \times 10^{17}/cm^3$.

Thereafter, an SiN_x film is deposited on the entire surface by about tens of nm by means of a plasma CVD method or the like, and formed in stripes of about 10 μm in width in a photolithography process, and using the obtained film as an etching mask, it is immersed in an etching solution of mixed solution of hydrochloric acid, hydrogen peroxide water, and water, and a mesa shape is formed. As a result, the width of the portion of the active layer 5 is about 9 μm.

Successively, by using the SiN_x film as a growth inhibition mask, a lower buried layer 7 made of p-type InP and an upper buried layer 8 made of n-type InP are laminated by the MOVPE method, both sides of the mesa are buried, and then, the SiN_x film is removed.

On the entire surface, the upper layer of the p-type cladding layer 9 made of InP with an impurity concentration of 5 to 7 × 10^{17}/cm^3 is formed in 2.5 μm, and a p-type contact layer 10 made of InGaAsP with an impurity concentration of about 5 × 10^{18}/cm^3 is formed to 0.3 μm.

Further, a p electrode 11 is formed on the top face of the p-type contact layer 10, and an n electrode 12 is formed on the downside of the semiconductor substrate 2, and thereafter, by cutting out in a length of 3 mm, an LR film 21 is applied to the front end face and an HR film 22 is applied to the rear end face, and thereby a laser structure is formed.

FIG. 11 is a diagram showing the current-output characteristic of the semiconductor laser 1 having such a configuration.

In FIG. 11, characteristic curve F represents the characteristic of the semiconductor laser in the numerical value example above, and characteristic curve F' shows the fiber output characteristic produced by optical coupling with the single mode optical fiber, for example, without a lens.

According to the semiconductor laser of this example, favorable characteristic that the coupling efficiency with the single mode optical fiber is about 80% is obtained.

5   The light confinement coefficient in the p-type cladding layer 9 of the semiconductor laser is 17%, which is substantially lowered as compared with the confinement coefficient 42% of the conventional structure.

10   The value of internal loss estimated from the actually manufactured semiconductor laser is 5 to 6 cm^{-1} in the conventional structure, and is improved to 3.0 cm^{-1} or less in this semiconductor laser.

Although the semiconductor laser is of a buried

15   structure, the invention can be similarly applied to the semiconductor laser of a ridge structure shown in FIG. 12.

In FIG. 12, an insulating layer 23 made of SiO_2 is formed on the p-type cladding layer 9 and p-type

20   contact layer 10.

Also in the case of the semiconductor laser of such a ridge structure, the n-type cladding layer 3 made of InGaAsP with higher refractive index than that of the p-type cladding layer 9 made of InP is used.

25   Accordingly, as in the example above, the light distribution can be biased to the n-type cladding layer 3 side, and the same laser light of high output is

obtained as explained above.

In the semiconductor laser described above, each layer is formed on the n-type semiconductor substrate 2. As shown in FIG. 13, however, even in the semicon-
5   ductor laser in which each layer is formed on a p-type semiconductor substrate 2', the same effects as above can be obtained by composing the n-type cladding layer 3 by using InGaAsP with a higher refractive index than that of the p-type cladding layer 9 made of InP.

10   In the foregoing semiconductor lasers, the bandgap wavelength of the outermost layer 4c of the first SCH layer 4 is set to be longer than the bandgap wavelength of the n-type cladding layer 3 made of InGaAsP. As shown in FIG. 14, however, the bandgap wavelength of
15   the outermost layer 4c (4N) of first SCH layer 4 may be set to be shorter than the bandgap wavelength of the n-type cladding layer 3 made of InGaAsP.

That is, in the semiconductor laser 1 of another embodiment in FIG. 14, the refractive index nN of the
20   outermost layer 4N of the first SCH layer 4 is set to be lower than the refractive index na of the n-type cladding layer 32 made of InGaAsP (na > nN) as shown in FIG. 14.

Also in the semiconductor laser 1 having the
25   layers formed thereon in such a manner, the same effects as the semiconductor laser 1 in the foregoing embodiments can be obtained by composing the n-type

cladding layer 3 by using InGaAsP with a higher
refractive index than that of the n-type cladding layer
9 made of InP.

In the semiconductor laser 1 of the other
5   embodiment in FIG. 14, since the refractive index nN of
the outermost layer 4N of the first SCH layer 4 is set
to be lower than the refractive index na of the n-type
cladding layer 3 made of InGaAsP, overflow of injected
carriers (holes) can be advantageously prevented.

10   Incidentally, in the semiconductor laser 1 of
the other embodiment in FIG. 14, the great and small
relationship of the refractive indexes of the layers is
set to be smaller as going away from the active layer
as shown below, as shown in FIG. 14, including the
15   refractive index ns of a layer having the lowest
refractive index among plural layers for composing
the active layer 5 is highest, and the refractive index
na of the n-type cladding layer 3 is higher than the
refractive index nb of the p-type cladding layer 9:

20    $ns > n1 > n2 > n3 >, ..., > nN > nb$
and

$na > nN.$

In addition, in the semiconductor laser 1 of
the other embodiment in FIG. 14, as mentioned above,
25   the refractive index nN of the outermost layer 4N of
the first SCH layer 4 is set to be lower than the
refractive index na of the n-type cladding layer 3 made

of InGaAsP (na > nN), and also the relationship is set
as follows:

ns-n1 > n1-n2 > n2-n3 >, ..., n(N-1)-nN

so that the refractive index difference between

mutually adjacent layers among the plural layers for

composing the first SCH layer 4 and second SCH layer 6

is set to be smaller as going from the active layer 5

to both the cladding layers 3, 9.

Further, in order that the thicknesses of the

layers are equal to each other, the relationship of:

t1 = t2 = t3 =, ..., = tN

is established.

This is applied as a partially modified form of

the refractive index characteristic (ns-n1 > n1-n2 >

2n-n3 >, ..., > nN-nb > nN-na) of the semiconductor

laser 1 in the first embodiment shown in FIG. 3.

Therefore, the configuration of the semiconductor

laser 1 of the other embodiment in FIG. 14 in which

the refractive index nN of the outermost layer 4N of

the first SCH layer 4 is set to be lower than the

refractive index na of the n-type cladding layer 3 made

of InGaAsP can be applied as a partially modified form

of the refractive index characteristic (ns-n1 = n1-n2 =

n2-n3 =, ..., = nN = nb) of the semiconductor laser 1

in the other embodiment shown in FIG. 9, being set so

that the refractive index difference between mutually

adjacent layers among the plural layers for composing

the first SCH layer 4 and second SCH layer 6 may be the same (ns-n1 = n1-n2 = n2-n3 =, ..., = nN-nb, provided that nN-nb > nN-na), and being set so that the thicknesses of the layers may be greater as being more

5   remote from the active layer 5 (t1 < t2 < t3, ..., tN).

Further, the configuration of the semiconductor laser 1 of the other embodiment in FIG. 14 in which the refractive index nN of the outermost layer 4N of the first SCH layer 4 is set to be lower than the

10   refractive index na of the n-type cladding layer 3 made of InGaAsP can be applied as a partially modified form of the refractive index characteristic (ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na) of the semiconductor laser 1 in the other embodiment shown in FIG. 10, being

15   set so that the refractive index difference between mutually adjacent layers among the plural layers for composing the first SCH layer 4 and second SCH layer 6 is smaller as going away from the active layer 5 (ns-n1 > n1-n2 > n2-n3 >, ..., > nN-nb > nN-na), and being set

20   so that the thicknesses of the layers is greater as being more remote from the active layer 5 (t1 < t2 < t3, ..., < tN).

In this semiconductor laser 1, the bandgap wavelength of InGaAsP for composing the n-type cladding

25   layer 3 is 0.97 μm. However, in the semiconductor laser 1 of the invention, by selecting the bandgap wavelength of InGaAsP in a range of 0.96 to 0.98 μm,

the width of the active layer 5 can be set at 7 to 14 µm.

In the semiconductor laser 1 of the invention, by selecting the bandgap wavelength of InGaAsP in a range of 0.96 to 0.98 µm, the laser light of high output can be applied into the single mode optical fiber while maintaining the fundamental lateral mode at the time of optical coupling with the single mode optical fiber.

FIG. 15 is a schematic diagram of optical coupling of the semiconductor laser 1 of the invention with an external single mode optical fiber 31.

In FIG. 15, the single mode optical fiber 31 has an anti-reflective (AR) film 32 formed on a light incident plane 31a.

As an example of optical coupling of the semiconductor laser 1 of the invention with the external single mode optical fiber 31, as indicated by solid line in FIG. 15, the central axis of the laser light emitted from one end face of the semiconductor laser 1 (LR side 21 in FIG. 15) is matched as far as possible with the central axis of a core 31b of the light incident plane 31a of the single mode optical fiber 31, and the one end face of the semiconductor laser 1 having the LR side 21 is disposed closely to the light incident plane 31a of the single mode optical fiber 31 having the AR film 32 (coupling without a lens).

Another example of optical coupling of the

semiconductor laser 1 of the invention with the
external single mode optical fiber 31 is indicated by
a broken line in FIG. 15, in which the central axis
of the laser light emitted from one end face of the
5   semiconductor laser 1 (LR side 21 in FIG. 15) is
matched as far as possible with the central axis of the
core 31b of the light incident plane 31a of the single
mode optical fiber 31, and the one end face of the
semiconductor laser 1 having the LR side 21 is disposed
10   by abutting against the light incident plane 31a of the
single mode optical fiber 31 having the AR film 32
(butt joint coupling).

As a result, the exit light from the LR side 21 of
the active layer 5 of the semiconductor laser 1 is
15   applied to the core 31b of the light incident plane 31a
of the single mode optical fiber 31.

According to this configuration, by expanding the
active layer width while maintaining the fundamental
lateral mode, the semiconductor laser 1 and the single
20   mode optical fiber 31 can be optically coupled at
a high coupling efficiency.

In the foregoing semiconductor lasers, the first
and second SCH layers 4, 6 are provided at both sides
of the active layer 5. However, the invention can be
25   also applied in another semiconductor light emitting
device, as shown in FIG. 16, such as a semiconductor
laser, an external resonator type semiconductor laser,

and a light emitting diode (LED), in which both the cladding layers 3, 9 are adjacent to both sides of the active layer 5, without forming the first and second SCH layers 4, 6.

5   Thus, in the semiconductor laser 1 of the invention, by using four element materials (In, Ga, As, P) in the n-type cladding layer 3, the bandgap wavelength of the n-type cladding layer 3 is set at 0.96 to 0.98 μm, and the width of the active layer 5 is

10   set at 7 to 14 μm.

Accordingly, in the semiconductor laser 1 of the invention, the active layer width is broader so as to be closer to the mode field diameter of the fiber, while maintaining the oscillation fundamental lateral

15   mode.   Therefore, for example, without using a lens, sufficient coupling efficiency with the single mode optical fiber is obtained, and the laser module can be lowered in cost.

In the semiconductor laser 1 of the invention,

20   moreover, since it is not required to use the taper optical waveguide for converting the spot size of the laser light according to the core diameter of the single mode optical fiber as in the prior art disclosed in patent document 1, the device length can be

25   shortened, and the device cost can be curtailed.

As described herein, the invention provides a semiconductor laser capable of coupling the laser

light of high output with the single mode optical fiber at low cost and at high coupling efficiency, while maintaining the fundamental lateral mode, without requiring the lens and other spot size converters

5   unlike the prior art, when optically coupling with the single mode optical fiber.